Idaho State University – Department of Physics

Spring 2009
PHYS 499 / PHYS 630
ACCELERATOR PHYSICS
3 credits

Instructor

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Course description and objectives

This course is an introduction to the physics of particle accelerators. It covers the basic concepts that are necessary to understand the use of accelerators in science and their applications in medicine and industry.

The main topics we will cover are the following: history of accelerators; electrostatic machines, linacs, cyclotrons, betatrons, synchrotrons; the concept of luminosity; acceleration and phase stability; transverse dynamics, weak and strong focusing; charged-particle optics; synchrotron radiation.

The course has four main goals:

→ to understand the main concepts, such as direct-voltage acceleration, resonant acceleration, phase stability, strong focusing, etc.;

→ to become familiar with the design principles of beamlines, linear accelerators and circular machines;

→ to become aware of the historical development of the discipline;

→ to develop skills for critical reading of the main research literature on the subject.

Prerequisites

The course is open to graduate students and to advanced undergraduates. Prerequisites are classical mechanics, electromagnetism, and special relativity at the undergraduate level. No previous knowledge of nuclear and particle physics or accelerators is necessary.

Special needs

Our program is committed to all students achieving their potential. If you have a disability or think you have a disability (physical, learning disability, hearing, vision, or psychiatric) which may need a reasonable accomodation, please contact the ADA Disabilites and Resource Center located in Gravely Hall, Room 123, (208) 282-3599 as early as possible.

Lecture schedule

We will meet in the conference room at the Department of Physics (PS 121) on Wednesdays between 10:00 am and 1:00 pm. We will take a 15-minute break around 11:30.

Here is a list of topics we will cover. This schedule is to be considered tentative.

Date	Topics
14 Jan	Review of mechanics, electromagnetism, and relativity.
21 Jan	History: electrostatic generators, linacs, cyclotrons, and betatrons.
28 Jan	History: synchrotrons, colliders.
04 Feb	Luminosity.
11 Feb	Dr. Stancari at JLab — no class.
18 Feb	Acceleration and longitudinal dynamics.
25 Feb	Dr. Stancari at CLAS12 workshop — no class.
04 Mar	Midterm exam.
11 Mar	Charged particle optics.
18 Mar	Transverse dynamics I.
25 Mar	Spring break — no class.
01 Apr	Transverse dynamics II.
08 Apr	Dispersion. Perturbations. Non-linearities and coupling.
15 Apr	Beam measurements.
22 Apr	Synchrotron radiation.
29 Apr	Review. Questions
01 May	Final exam.

Course materials will be posted on the course Moodle website, `<http://elearning.isu.edu/moodleisu>`.

Grading

Student learning is evaluated through homework, midterm and final exams, and an essay on a research paper, according to the following table:

homework	30%
midterm exam	30%
essay	10%
final exam	30%
	100%

Homework consists of exercises and problems. Collaboration among students is encouraged, but each student has to turn in his or her own hand-written copy. The deadline is indicated on the homework itself, and it is typically one week after the homework is distributed.

The **midterm exam** and the **final exam** consist of a combination of multiple-choice questions, problems, and short essay questions. They are in-class, closed-book exams. However, the student may come to the exam with his or her own note sheet (or 'cheat sheet'), provided the following guidelines are followed:

- the note sheet must be in letter-paper format (or smaller) and written on one side only;
- note sheets can contain any kind of information: formulas, physical constants, problems with solutions, etc.
- students may prepare their note sheets together with other students, but each student must bring his or her own hand-written sheet — no photocopies, typed notes, or notes written by somebody else;
- the note sheet must be turned in together with the exam; if they wish, students may have their note sheet returned to them after the exam is graded.

The critical **essay** on a research paper is an important part of grading. Its purpose is to evaluate the ability of the student to read the research literature critically and understand the context in which it is carried out.

> It is of great advantage to the student of any subject to read the original memoirs on that subject, for science is always most completely assimilated when it is in the nascent state. *–James Clerk Maxwell*

Within the first two or three weeks of class, students are expected to choose one research article to work on. Below is a list of suggested 'classic' papers to choose from:

- A. Einstein, On the Electrodynamics of Moving Bodies (English translation of *Zur Elektrodynamik bewegter Körper*), Annalen der Physik **17**, 891 (1905).

- R. Wideröe, A New Principle for the Generation of High Voltages, Archiv für Elektrotechnik **21**, 387 (1928).
- D. H. Sloan and E. O. Lawrence, The Production of Heavy High Speed Ions Without the Use of High Voltages, Phys. Rev. **38**, 2021 (1931).
- E. L. Ginzton, W. W. Hansen, and W. R. Kennedy, A Linear Electron Accelerator, Rev. Sci. Instrum. **19**, 89 (1948).
- J. D. Cockcroft and E. T. S. Walton, Experiments with High Velocity Positive Ions, Proc. Roy. Soc. (London) A **129**, 477 (1930); Proc. Roy. Soc. (London) A **136**, 619 (1932); Proc. Roy. Soc. (London) A **137**, 229 (1932); Proc. Roy. Soc. (London) A **144**, 704 (1934).
- R. J. Van de Graaff, J. G. Trump, and W. W. Buechner, Electrostatic Generators for the Acceleration of Charged Particles, Rep. Prog. Phys. **11**, 1 (1948).
- E. O. Lawrence e M. S. Livingston, The Production of High Speed Light Ions Without the Use of High Voltages, Phys. Rev. **40**, 19 (1932).
- L. H. Thomas, The Paths of Ions in the Cyclotron. I. Orbits in the Magnetic Field, Phys. Rev. **54**, 580 (1938).
- E. O. Lawrence, The Evolution of the Cyclotron (1939 Nobel Lecture, delivered in 1951).
- D. W. Kerst, The Acceleration of Electrons by Magnetic Induction, Phys. Rev. **60**, 47 (1941).
- D. W. Kerst and R. Serber, Electronic Orbits in the Induction Accelerator, Phys. Rev. **60**, 53 (1941).
- V. Veksler, A New Method of Acceleration of Relativistic Particles, Journal of Physics, U.S.S.R. **9**, 153 (1945).
- E. M. McMillan, The Synchrotron — A Proposed High Energy Particle Accelerator, Phys. Rev. **68**, 143 (1945).
- E. D. Courant, M. S. Livingston, and H. S. Snyder, The Strong-Focusing Synchrotron — A New High Energy Accelerator, Phys. Rev. **88**, 1190 (1952).
- E. D. Courant and H. S. Snyder, Theory of the Alternating-Gradient Synchrotron, Ann. Phys. **3**, 1 (1958), reprinted in Ann. Phys. **281**, 360 (2000).

A copy of each paper in PDF format will be available from the course website.

It is possible to choose a paper that is not on the list, especially if you want to study a particular subject in more depth. In this case, your choice must be discussed with the instructor.

Here are some suggestions on **how to prepare a good essay**:

1. Skim through the article, looking at the title, introduction, conclusions, and general structure.
2. Read the paper from beginning to end in one sitting, even if you do not understand everything.

3. Read the paper again, paying attention to its logic structure: What problems are the authors trying to solve? What steps did they take? What conclusions did they draw?

4. Read the paper again, this time paying attention to details. Try to understand each sentence. Look up terms you do not know. Make a glossary of the terms that are most relevant for the topic of interest. For instance, in Courant and Snyder's paper "Theory of the Alternating-Gradient Synchrotron," the terms 'strong focusing' and 'transition energy' are definitely relevant, whereas 'magnetic field' is important but not typical of the subject being discussed.

5. Once you are sure you understand the paper in detail, judge *on your own* whether its main statements are true or not. The authors may have lacked information; they may have made statements which do not correctly follow from previous statements; or they may have omitted relevant information.

6. Reflect on the relevance and applications of the results and ideas you read about.

At this point, you are ready to write your essay (a few hand-written or typed pages should be enough) summarizing your critical work. In it, one should be able to find the answers to the following questions (not necessarily in this order):

- What is the paper about as a whole? What are its main parts?
- What is being said in detail and how? What are the main terms or keywords?
- Are all the main statements true? Were the authors informed, logical and complete?
- What is the relevance of this paper? What applications does it have? How could the subject be expanded?

The essay must be turned in by **April 15, 2009**.

Final letter grades will be assigned according to the percent grade g:

$93 \leq g$	A
$91 \leq g \leq 92$	A-
$86 \leq g \leq 90$	B+
$84 \leq g \leq 85$	B
$81 \leq g \leq 83$	B-
$76 \leq g \leq 80$	C+
$74 \leq g \leq 75$	C
$71 \leq g \leq 73$	C-
$66 \leq g \leq 70$	D+
$64 \leq g \leq 65$	D
$61 \leq g \leq 63$	D-
$g \leq 60$	F

Textbooks

Required

D. A. Edwards and M. J. Syphers, An Introduction to the Physics of High Energy Accelerators (Wiley, 1993)

A. Sessler and E. Wilson, Engines of Discovery: A Century of Particle Accelerators (World Scientific, 2007)

Other useful resources

M. S. Livingston and J. P. Blewett, Particle Accelerators (McGraw-Hill, 1962)

M. S. Livingston, The Development of High-Energy Accelerators (Dover, 1966)

M. Sands, The Physics of Electron Storage Rings: An Introduction, Stanford Report SLAC-121 (1970), `<http://ccdb4fs.kek.jp/cgi-bin/img_index?197708303>`

C. Pellegrini and A. M. Sessler, The Development of Colliders (American Institute of Physics, 1995)

A. W. Chao and M. Tigner, Handbook of Accelerator Physics and Engineering (World Scientific, 1999)

A. W. Chao, Resource Letter PBA-1: Particle beams and accelerators, Am. J. Phys. **74**, 855 (2006)

T. P. Wangler, RF Linear Accelerators (Wiley, 2008)